VI-2. TECHNIQUES FOR PROVIDING TWM'S WITH WIDE INSTANTANEOUS BANDWIDTHS

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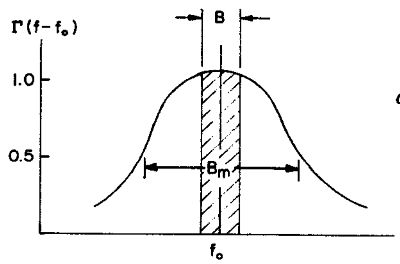
The paramagnetic material in a conventional TWM is uniformly distributed in a slow-wave structure located in a homogeneous DC magnetic field. The spin distribution-function has a Lorentzian shape which constitutes a fixed relationship between Gain (db) and 3 db bandwidth, namely, $B_3 = B_m \sqrt{\frac{3}{G_{db}-3}}$. By applying an inhomogeneous DC magnetic field, we can overcome this limitation and make gain and bandwidth both independent variables.

The amplification bandwidth of the TWM can be increased by effectively dividing the paramagnetic material into parallel filaments or series sections, each of which amplifies a separate portion of the desired bandwidth. In the series-connection, however, it is undesirable, for reasons of noise performance, to have any portion of the original spectrum travel through a significant length of the structure (where a loss would occur) before receiving some gain. Either approach can be realized by properly varying the spatial distribution of the DC magnetic field applied to the paramagnetic material. Limited investigations have been conducted in the past (References 1, 2, and 3).

In a TWM, the product $G_{(db)} \cdot B$, is proportional to the number of useful net spins. If we define an efficiency-factor, α, as the ratio between the number of useful net spins and the number of total available net spins $\alpha = \frac{N_u}{N_t}$ then: $G_{(db)} \cdot B = K \alpha N_t$, where K is a proportionality-factor. We can express the gain of TWM in general as $G_{(f)db} = G_{(fo)db} \cdot \Gamma(f-f_o)$ where $\Gamma(f-f_o)$ is the normalized line-shape function ($\Gamma(o) = 1$). For high $G_{(f_o)db}$ only a slight change in $\Gamma(f-f_o)$ is necessary to make $G_{(f)db} = G_{(f_o)db} - 3$. This is illustrated in Figure 1 for a homogeneous maser (Lorentzian shape). We see that the efficiency factor, α, is very poor:

$$\alpha \approx \frac{B_3}{\frac{\pi}{2} B_m}.$$



$$\Gamma(f-f_o) = \frac{1}{1+\left(2\frac{f-f_o}{B_m}\right)^2}$$

$$\alpha = \frac{\int_{-\frac{B}{2}}^{+\frac{B}{2}} \Gamma(f-f_o)\,df}{\int_{-\infty}^{+\infty} \Gamma(f-f_o)\,df} \approx \frac{B}{\frac{\pi}{2} B_m}$$

Figure 1. Lorentzian Line Shape Function with Indicated Useful Portion

It will be obvious that in order to maximize α, the line shape function has to be as close to a rectangle as possible. By applying an inhomogeneous magnetic field, each filament or series section can be regarded as an elementary TWM with its own center frequency. The total TWM system is then the result of a large number of stagger-tuned elementary TWM's each having a Lorentzian shape (Figure 2). We assume that the skirts of $\Gamma(f-f_o)$ in the maximum flat case are still approximately determined by the Lorentzian shape. The relationship between normalized gain (db) and normalized bandwidth is given in Figure 3. The tradeoff between bandwidth and unstaggered gain (when designing a staggered TWM with a certain bandwidth and a predetermined gain) for the case of ruby ($B_m \approx 60$ mc), is shown in Figure 4.

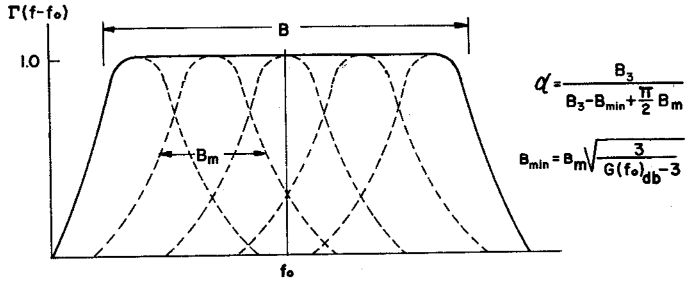


Figure 2. Broad-Banding by DC Field Staggering

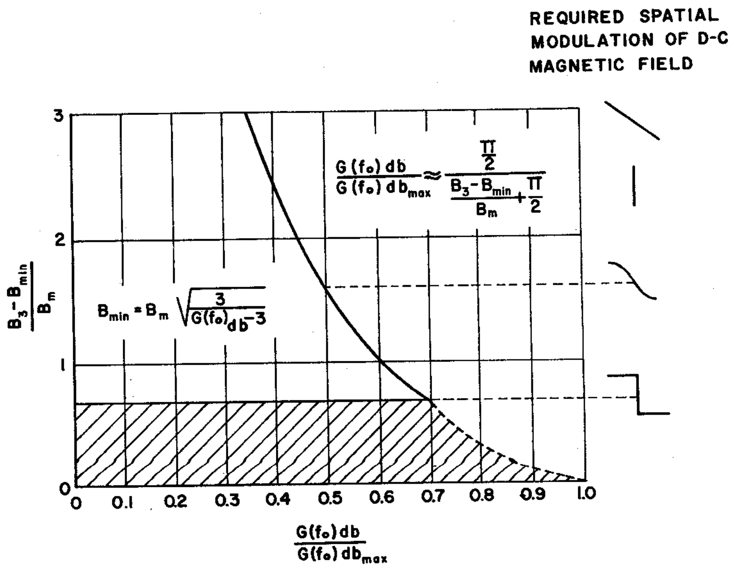


Figure 3. Normalized Gain-Bandwidth Function

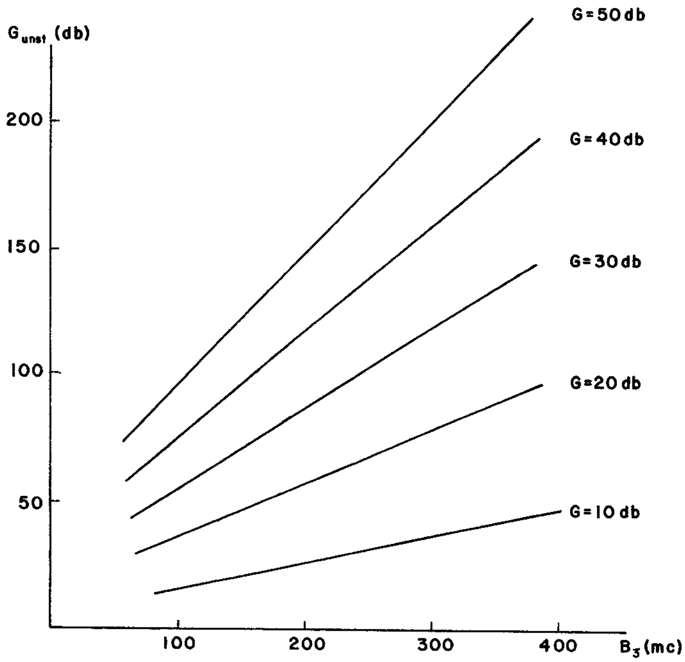


Figure 4. Unstaggered Gain as a Function of Staggered Bandwidth with Staggered Gain as Parameter (Paramagnetic Material Ruby, $B_m \approx 60$ mc)

Assuming for a moment that the paramagentic resonance alone determines the frequency response of the TWM, we can calculate the required DC field distribution in case of one-dimensional staggering For two characteristic points, $\frac{B_3 - B_{min}}{B_m} = 0.7$ and 1.6, the required changes of magnetic field as a function of distance, are of a simple analytical form; a step and a cosine respectively.

For larger and larger bandwidths the required shape becomes more linear. Below $\frac{B_3 - B_{min}}{B_m} = 0.7$, it is impossible to obtain a flat response. The best we can do here is the single step. The exact shape of the gain-bandwidth curve in this region cannot be given because it is dependent on $G_{(db)max}$. The above results are indicated in Figure 3.

The relationships discussed above are for the electronic gain (G_e) only. If we include the effect of losses we have: $(G_{net})_{db} = (G_e)_{db} - L_{db}$. The losses can be divided into ferrite loss (L_f) (from the isolators) and structure losses (L_s). The forward loss is proportional to the required backward isolation which in turn is proportional to the net gain. $(L_f)_{db} = c(G_{net})_{db}$ (c is a proportionality constant). This relation holds only when the signal level over the total bandwidth is gradually increasing in the length direction of the TWM. Thus·

$$G_{net_{db}} = \frac{(G_e)_{db} - (L_s)_{db}}{1 + c}$$

from which we see that the structure losses set the ultimate limit to the bandwidth.

As the electronic gain is approximately inversely proportional to the absolute temperature of the TWM, whereas the structure losses stay about constant at very low temperatures, we see that decreasing the temperature is a very powerful approach to obtain extremely wide bands especially when G_s approaches L_s.

Until now, we have assumed that the paramagnetic material was effectively pumped for the whole bandwidth. One pump-klystron, however, can cover only a limited frequency range.

For a 5 gc TWM with a 1-4 pumping scheme ($f_p \approx 35$ gc) it has been found experimentally that one pump klystron is needed for every 80 to 100 mc instantaneous signal-bandwidth.

From considerations of noise performance and minimum ferrite losses, we can conclude that staggering along x- or y-axis is superior to staggering along the z-axis (Figure 5).

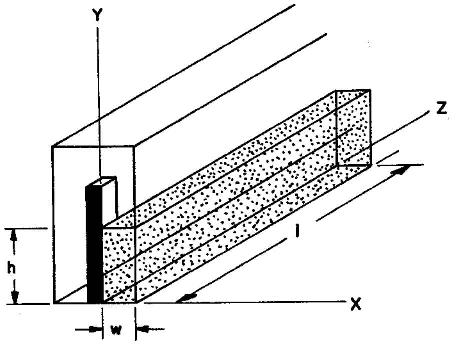


Figure 5. Coordinates and Parameters of Slow-Wave Structure

To keep the required gradients to a minimum, staggering along the height of the ruby is chosen ($h > W$). For staggering along the z-axis, the assumptions made are tolerable.

For staggering along x- or y-axis, however, we have to take into account that the r.f.-field configurations are functions of x and y so that the DC-field distributions, found above, have to be corrected by a proper weighting function.

The main part of the weighting function is determined by the current distribution along the fingers of the comb structure. A typical distribution is given in Figure 6. Since the gain db is proportional to H_{rf}^2 and thus to I^2 it is seen that the frequencies, taken care of in the bottom part of the ruby, are strongly favored compared to those in the top part.

A special minimum mass shimming technique has been developed that makes it possible to meet the field requirements in the region $\frac{B_3 - B_{min}}{B_{max}} > 2$ very satisfactorily. Experimental results will be presented at this meeting.

ACKNOWLEDGMENT

This work was supported by the Research and Technology Division, Rome Air Development Center under Contract AF30(602)-2989.

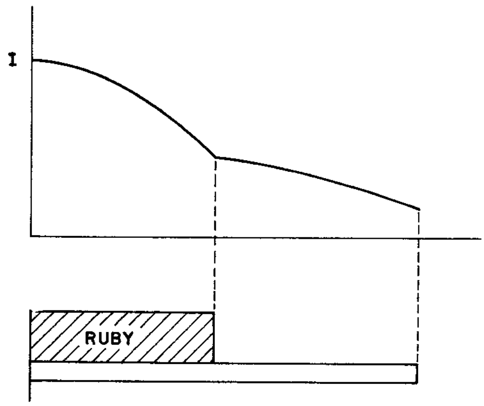


Figure 6. Typical Current Distribution Along the Fingers of the Comb-Structure

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